Study on *Sonneratia apetala* productivity in restored forests in Leizhou Peninsula, China

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Abstract: The exotic *Sonneratia apetala* in Leizhou Peninsula, has shown outstanding fast-growing ability in restored mangrove forests, at the middle and high tide intertidal zone, with year-round fresh water input from drainage. By setting plot and selecting standard tree, investigation and measurement on height growth, diameter growth, biomass, productivity, and so on, were made in a *S. apetala* plantation at age of six at Lanbei, Fucheng, Leizhou Peninsula in May 2001. The investigating results showed that the mean annual height growth of plantation was 2.03 m and mean annual growth of diameter at breast height (DBH) was 2.35 cm. There exists a significant correlation between the diameter at ground surface (DGS) and DBH. The average biomass of a single standard tree in dry weight was 95.647 kg/m^2. A ratio of above-ground biomass to under-ground biomass was 1.60. The stand biomass of unit area was 22.955 kg/m^2, singletree wood volume was 88.23 dm^3, and the annual wood volume productivity (P_A) of the same year was 0.407. The forest energy accumulation was 424.851 MJ/m^2, with annual solar energy fixing rate of 40.68 $\times 10^{-7}$%. It is concluded that *S. apetala* species had characteristics of outstanding high biomass accumulation and could be used as coastal planting tree species in southern China.

Key words: *Sonneratia apetala*; Mangrove; Biomass; Leizhou Peninsula
CLC number: S 758.1; S728.6 **Document code**: A **Article ID**: 1007-662X(2001)04-0229-06

Introduction

Mangrove ecosystems are forest associations of the intertidal zones at tropical and subtropical coastal areas, and range from the vast riversides and estuaries of eastern and western worlds. Mangrove associations consist of mangrove and semi-mangrove tree species and other accompanying species and their bio-physical environments (Tomlinson 1986). Mangrove forests are unique coastal landscapes, since long named as "Forests in Sea", with important ecological functions (Ronnback 1999) and precious natural resources with a high productivity (Saenger & Snedaker 1993).

Along with the progress of worldwide mangrove research, it is highly recognized that mangroves play a major role in maintaining the stability of the coastline and in protecting wildlife. As research results show, the value of mangrove ecosystems in China adds up to 173 282 RMB¥/hm^2·a^{-1} (20 877 US$/ hm^2·a^{-1}) (Han *et al.* 2000), and the world mangroves contributing to captured fisheries is 750-16 750 US$/ hm^2·a^{-1} (Ronnback 1999). In addition, ecologists are fully aware of the role of mangroves in supporting inshore fishery and serving as nurseries and refuges (Chullasomand & Martosubrota 1986; Saenger 1987; Field 1999). Still few data are available to support these relations, such as the nutritious correlation between mangrove and its environment (Lee 1999). Furthermore, research is needed into mangrove growth capacities in different environments.

Study on mangrove productivity began in Florida, USA, in the 1960s, and three ecosystem-level hypotheses were formulated regarding salt-marsh estuaries: the energy from tidal subsidy, outwelling and detritus-based food chains were proposed to interpret to support these ecosystems with high productivity (Odum 1980). The study has developed into an advanced stage and now considers all biological and physical factors from every scientific field (Lee 1999). In China, research has been carried out on mangrove species components, distribution areas, biodiversity and utilization, and also on subjects of detritus, biomass, energy, pollutant purification and acclimatization; planting trials were carried out (Lin 1990, 1993, 1999, 2000; Lin & Fu 1995; Zhou & Yin 1998). Though, the researches in China didn't study actual on-the-spot ecological processes, and the focus of restoration ecology (Ellison 2000), some preliminary mangrove studies in Leizhou Peninsula were carried out on associations and distribution areas (Chang

Foundetion item: The paper was supported by the project of integrated mangrove management and coastal protection (IMMCP) in Leizhou Peninsula, Guangdong Province.
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Received date: 2001-07-11
Responsible editor: Zhu Hong

et al. 1957), plant introduction and planting techniques (GCIG 1987; Wu *et al.* 2000; Zheng *et al.* 1999).

The mudflats and mangrove areas of Leizhou Peninsula are listed as important lands for artificial ecological rehabilitation in China. The provincial mangrove and bird reserves were first set up in Gaoqiao in 1990, covering 2 000 hm^2. On December 8, 1997, the Chinese State Government issued Document [1997] 109 to announce the setting up Zhanjiang National Nature (Mangrove) Reserve. During the passed 15 years, local coastal governments have taken effective planting initiatives for local species such as *Kandelia kandel* and *Avecinna marina*, and the species *Sonneratia apetala* have been successfully introduced since 1993.

This paper presents the growth data and models of a *S. apetala* plantation at age of six after its successful introduction in Lanbei, Leizhou City.

Natural condition of the study plot

The *Sonneratia apetala* Buch.-Ham., forest plantation stand is distributed at Lanbei, Fuchen, Leizhou City (109°03′E, 20°30′N). The climate can be characterized as the most southern subtropical monsoon, with an annual mean temperature of 22.9 °C and mean monthly temperatures as shown in Table1. The annual mean precipitation is 1711 mm. The forest was planted at the land-ward side of the intertide, with surrounding land reclaimed as fishponds. Irregular tides affect the stand, and the ground surface is about 1.5 m under water at high tide, and 0.6-1.2 m above water at low tide. A freshwater channel passes through the edge of the woodland and provides year-round fresh water from the drainage in a sea-dyke. The forest soil is a mangrove acid soil, being dark soil with lots of organic materials at a depth of 0-10 cm, gray at a depth of 10-40 cm, and mixed color or yellow at a depth below 40 cm. The pH values were 6.8 at ground level, 5.8 at a depth of 20 cm, 4.5-5.0 at a depth of 40 cm, and 6.0 at a depth of 60 cm.

Table 1. Mean monthly temperature (MMT) at Leizhou estuary (GCIG 1987) (°C)

Index	Jan.	Feb.	Mar.	April	May	Jun.
MMT	15.5	16.1	19.6	23.5	27.0	27.9
Index	July	Aug.	Sept.	Oct.	Nev.	Dec.
MMT	28.4	27.8	26.9	24.3	20.6	17.3

The *S. apetala* forest in Lanbei was planted in August 1995 through introducing seedlings from Donzaigang, Hainan Island. The spacing of plant (0.67 hm^2) was 2 m×2 m for 166 seedlings planted (2500 plants/hm^2). This was the first trial for *S. apetala* in the Peninsula.

Research methods

One square plot of 5 m × 5 m was set out and the *S. apetala* forest at age of six was surveyed (Yu *et al.* 1993). A tree with closest growth value of the plot trees' average was sampled as the standard tree and cut for further examination in May 2001. A soil pit with 1 m^2 surface level area to a depth of 100 cm was designed to be investigated the root biomass distribution of the stand plot. The roots in the soil were collected by washing out the soil in a 0.1 cm diameter mesh net. All plant organs were weighed, and a part of each organ was brought to a laboratory for establishing of its water content percentage, by way of a dehydration process with temperatures of 85-105 °C. Their organ's caloric values were tested using a combustor. Of 60 randomly selected trees, the diameters at ground surface (DGS) and DBH were determined to establish their correlation as reference data to the results of plot survey. The leaf area index (LAI) was calculated. Six discs at every two meters along the trunk of a standard tree were sawn free to determine the annual diameter growth. The annual height growth was measured every year in May since planting. The wood volume of the standard tree was calculated according to the following formulas (Lin *et al.* 1992):

$$f = \frac{V}{S \times h} \tag{1}$$

Where:

f-- standard tree form index;
V-- standard tree volume;
S-- DBH section area;
h-- tree height.

$$P_A = \frac{V_{2001}}{V_6} \tag{2}$$

Where:

V_{2001}-- wood volume increase;
P_A-- current year wood volume productivity;
V_6-- total volume.

Caloric values were tested by using a combustor of WGR-1G type computerized caloric detector (made by Changsha Instruments Factory, Hunan, China); the tests were conducted by the method as described in the manual and according to related references (Ren *et al.* 1999; Lin *et al.* 2000). Samples of plant organs used had to pass a No.40 screen mesh sieve. Each sample was tested three or six times, with an error deviation below 150 J/g. The ash contents of all samples were determined after burning at 560 °C for 4 h.

Results and analysis

Results of the investigated plot

The single layer forest includes *Kandelia candel* (L.)Druce, *Clerodendron inerme* (L.) Gaertn., *Aegiceras corniculatum* Blanco., *Bruguiera gymnorrhiza* (L.)Poir., *Acrostichum aureum* L., *Pluchea indica* (L.) Less, *Impomoea pes-caprae* (L.)Sweet., *Sporobolus virginicus* (L.)Kunth as component species, but all these species are

distributed around forest edge. The crown range of a single standard tree of *S. apetala* was on average 2 m×3 m wide, forming the forest's coverage rate of 0.9. The LAI was 3.6, and pneumatophores were present at 339 pecies/m^2. The plot of 5 m × 5 m contained six trees with an average height of 12.18 m, average DBH of 17.09 cm, and mean annual height growth of 2.03 m. the mean annual DBH growth was 2.84 cm in Table 2.

Table 2. The tree indexes of Lanbei plot

Plant No.	Height/m	DGS/cm	DBH/cm
1	14.10	26.67	7.99+14.52
2	4.80	8.32	4.95 (dead)
3*	13.70	18.37	14.58
4	13.50	22.45	13.52+4.76
5	12.70	21.59	9.29+12.22+4.30
6	14.30	18.91	16.42
Average	12.18	19.37	17.09

Notes: *-- selected as standard tree; +-- indicates several figures measured for each of the main branches sharing a same base tree trunk; DGS--- diameter at ground surface; DBH--- diameter at breast height.

Correlation between diameter at ground surface (DGS) and diameter at breast height (DBH)

The correlation between DGS (Y) and DBH (X) is obviously coordinate (at level of 0.01) as:

$$Y = 3.7881+1.1862X; \quad (3)$$

$r = 0.8565$, as shown in Table 3.

The average DGS and DBH do not correspond with the figures of Table 2, mainly because of 50% of the plot's trees with 2-3 trunks under 1.3 m high from the ground surface. Therefore, the standard tree of No.3 with DBH of 14.58 cm was selected, as it was the closest value to the average DBH surveyed randomly.

Biomass

Underground biomass

In the plot, an underground biomass (dry weight) of the *S. apetala* forest was 8.838 kg/m^2, which equals 5.991 kg/m^{2}of the root biomass plus 2.847 kg/ m^2 of mean underground trunk biomass. A major contribution of large and fine roots was shown in Table 4. The roots were mainly concentrated at a depth of 20-40 cm (51.22 %).The soil surface layer contained lots of fine roots.

Table 3. The correlation between DGS (Y) and DBH (X) of *Sonneratia apetala* in Lanbei plot (cm)

Factor	Number	Average DGS/DBH	$x\partial_{n-1}$	Correlation	r value
DGS (Y)	60	20.50	5.8071	Y=3.7881+1.1862X	r=0.8565**
DBH (X)	60	14.09	4.1928		

Aboveground biomass

The results showed that the standard tree's aboveground biomass was 58.822 kg/plant (dry weight), and then the stand aboveground biomass was 14.117 kg/m^2 (data were obtained through the calculation formulation: 58.822 kg/plant × 6 plants/25 m^2) as shown in Table 5.

The total biomass of single standard tree in dry weight was 95.647 kg, which gives a stand biomass of 22.955 kg/m^2. The ratio of aboveground biomass to underground biomass was 1.60. The ratio of wood volumes in each year from 1996 to 2001 was 0.22 (1996), 2.33 (1997), 12.37 (1998), 29.24 (1999), 52.34 (2000), 88.23 (2001), respectively (Table 6). The annual biomasses of *S. apetala* could be calculated as 0.239 kg (1996), 2.526 kg (1997), 13.421 kg (1998), 31.698kg (1999), 56.740 kg (2000), 95.647 kg (2001), and the accumulating biomasses per square meter for the standard tree as 0.057 kg/m^2 (1996), 0.606 kg/m^2 (1997), 3.221 kg/m^2 (1998), 7.608 kg/m^2 (1999), 13.618 kg/m^2 (2000), 22.955 kg/m^2 (2001). The biomass growth is calculated at 9.337 kg/m^2 in 2001.

Table 4. Root biomass distribution of *Sonneratia apetala* plantation

Soil depth/cm	Total biomass /kg·m^{-2}	Percentage (%)	Diameter/cm Large >1	Middle 0.5-1	Small 0.2-0.5	Fine <0.2
0-20	1.427 2	23.82	0.235 2	0.196 0	0.079 6	0.916 4
20-40	3.068 4	51.22	1.898 4	0.286 0	0.132 4	0.751 6
40-60	1.069 6	17.85	0.497 2	0.137 6	0.095 2	0.339 6
60-80	0.240 4	4.01	0.000 0	0.016 0	0.100 8	0.123 6
80-100	0.185 2	3.09	0.000 0	0.000 0	0.000 0	0.185 2
Total	5.990 8	100	2.630 8	0.635 6	0.408 0	2.316 4
Percentage (%)	100	--	43.91	10.61	6.81	38.67

Wood volume growth

The annual wood volumes as shown in Table 6 were calculated, through measuring the discs and the height growth records of the selected standard tree. The volume shape index (f) shows that f will decrease, as a tree grows older. When f_6= 0.042, then the wood volume growth model is as followed:

$$V=0.042\times 1/4\ D^2\times h=0.0105\ D^2h \quad (4)$$

Where:

V-- wood Volume; D—DBH; h-- tree height

$$P_A=\frac{V_{2001}}{V_6}=(88.23-52.34)/88.23=0.407 \quad (5)$$

Where:

P_A -- annual wood volume productivity;

V_{2001}--wood volume growth;

V_6-- total wood volume.

As shown from the disc data analyses, the single standard tree volume was 88.23 dm^3, the stand wood volume per square meter, 21.175 dm^3. In 2001, wood growth volume of single tree was 35.89 dm^3, and wood volume productivity (P_A) of the same year was 0.407. Compared with the research data as reported by Lin Peng *et al.* (Lin *et al.* 1990; 1992), P_A of *K. kandel*, *Bruguiera sexangula, and A. marinna* was 0.09, 0.026, and 0.061 respectively, so it can be concluded that *S. apetala* has an outstanding high wood volume productivity.

Ash content

The ash contents of the plant organs of *S. apetala* showed obviously differences (1.91% - 26.60%), and the descending order was: fine roots > middle roots > large roots > leaves > barks > underground trunk > fruits > branches > trunk (Table 5).

Table 5. Biomass and fixed energy of *Sonneratia apetala* at age of six

Organs	Dry weight/kg	Ash content (%)	GCV/kJ·g^{-1}	AFCV/kJ·g^{-1}	Fixed/MJ	Forest/MJ·m^{-2}
Roots	5.990 8					107.190
Fine root Φ<0.2cm	2.316 4	26.60	13.275	18.086	41.894	41.894
Middle root Φ0.2-1cm	1.043 6	25.72	12.807	17.242	17.994	17.994
Large root Φ>1.0cm	2.630 8	22.78	13.886	17.980	47.302	47.302
Under ground trunk	11.864	7.11	16.738	18.019	213.777	51.307
Trunk	35.327	1.91	18.478	18.838	665.490	159.718
Bark	8.378	7.27	17.057	18.355	153.778	36.907
Branch	11.872	4.37	17.868	18.685	221.828	53.239
Leaf	2.377	13.10	18.433	21.212	50.421	12.101
Fruit	0.211	6.38	19.573	20.907	4.411	1.059
Flower	0.657	13.05	18.365	21.121	13.877	3.330
Total						424.851

Notes: GCV--- gross-caloric-values; AFCV---ash free caloric values.

Table 6. Disc data and calculation of sampled wood growth of the standard *S. apetala* tree in Lanbei plot (cm)

Disc No. (Height/m)	First year (1996)	Second year (1997)	Third year (1998)	Fourth year (1999)	Fifth year (2000)	Sixth year/include bark (2001)
0(base)	1.2	3.4	6.7	8.6	11.3	14.6/15.0
1(2m high)	1.1	2.7	6.0	8.1	10.3	12.2/12.4
2(4m high)	-	1.3	3.8	7.2	9.5	11.3/11.6
3(6m high)	-	-	3.1	5.2	7.4	9.3/9.6
4(8m high)		-	-	3.1	5.8	7.7/8.0
5(10m high)	-	-	-	-	3.4	5.3/5.5
6(12m high)	-	-	-	-	-	3.3/3.5
Height* (m)	2.5	4.8	7.3	9.4	11.5	13.7
Diameter (cm)	1.2	2.7	6.3	8.6	11.3	14.0/14.58
Wood Volume** (dm^3)	0.22	2.33	12.37	29.24	52.34	88.23/89.52
Volume index (f)	0.071	0.084	0.054	0.053	0.045	0.042/0.039

Notes: *-- the average forest height recorded in May of each year; **-- wood volume between two discs (V) = ($S+S^{1/2}S'^{1/2}+S'$) *----h/3=3.1416/3/4*h* ($D^2+D'^2+DD'$), S,S' are discs' section areas of two neigbor discs at the same age, and D,D' are discs' diameters of two neigbor discs at the same age; h is height.

Unit energy accumulation

In Table 5, the unit energy accumulation for the forest was 424.851 MJ/m^2. Based on tests of ash free caloric values (AFCV) (which equals gross-caloric-values (GCV) / non-ash-weight), the order of AFCV (17.242 - 21.212 kJ/g) of *S. apetala* organs was: Leaf > Flower > Fruit > Trunk >

Branch > Bark > Fine root > Underground trunk > Large root > Middle root.

Annual solar energy-fixing rate

As indicated by theoretical data (GCIG 1987), the regional annual solar energy in Leizhou city is 4711.7 TJ/m^2. The energy accumulation of *Sonneratia apetala* forest was calculated at 424.851 TJ/m^2. In relation to the ratio of wood volumes of each year, the fixed energy accumulation of the same year was 172.820 TJ/m^2, and annual transfer rate of solar energy fixed into the forest was 40.68×10^{-7}%.

Conclusions

Forest productivity is measured through its biomass and caloric value and presents its current status in solar energy utilization (Lieth & Whittaker 1985). The exotic species *S. apetala* has shown outstanding growth ability in the middle and high tide lines of intertidal environments, with a year around fresh water drainage input. For *S. apetala* plantation at age of six in Lanbei, Leizhou Peninsula, its mean annual height growth was 2.03 m, and mean annual DBH growth was 2.35 cm. The DGS and DBH of the 60 selected tress show an obvious correlation at 0.0l level (DGS = 3.788 1+1.186 2DBH, r=0.856 5**).

The single tree's average biomass in dry weight was 95.647kg. The ratio of aboveground biomass to underground biomass was 1.60, the biomass per square meter 22.955kg, wood volume for singletree 88.23 dm^3, and the standard wood volume per square meter was 21.18 dm^3. The yearly wood volume productivity (P_A) was calculated at 0.407. The forest energy accumulation was 424.851 MJ/m^2, and annual solar energy fixing rate in the year 2001 was 40.68×10^{-7}%.

The presented results suggest using sufficiently *S. apetala* in coastal afforestations, as it could produce high biomass accumulation and could increase coastal protection as well as provide habitats for birds and other biodiversity. Furthermore, with its fast growing characteristics, this mangrove species provides new possibilities in afforestation in mangrove conservation management. The tree can bear lots of fruits, which could be regarded as an alternative and sustainable resource for economic improvement of the local communities.

Acknowledgements

The authors thank the assistant professor Huang Yueqiong, Miss Wu Xiaofeng and Forestry majoring students of Zhanjiang Ocean University for carrying out this study in the fields; and also thank local mangrove patrol servicemen.

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